3.5.2 COLOR DIFFERENCE DECODING

The color difference decoding is similar to the luminance decoding and is shown in Fig. 3-11. The same techniques are used for decoding the color difference signals and producing a 720 active line per frame signal for display.

3.5.3 REMATRIXING AND GAMMA CORRECTION

After decoding, 720 active lines of luminance and color difference signals are available for rematrixing into RGB. As mentioned previously, these signals are rematrixed according to the SMPTE Step II process and gamma corrected before display.

Color Difference Decoding

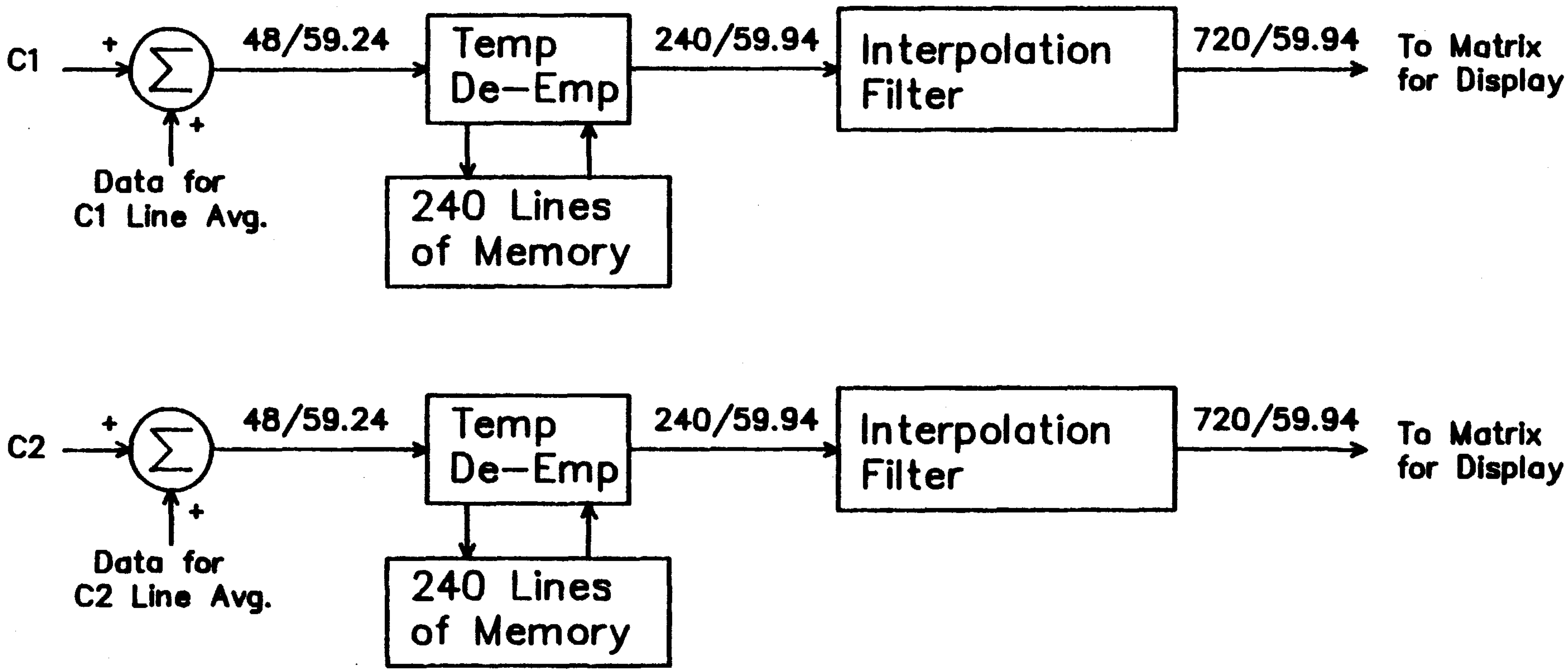

Figure 3-11

Zenith
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fig_3-11

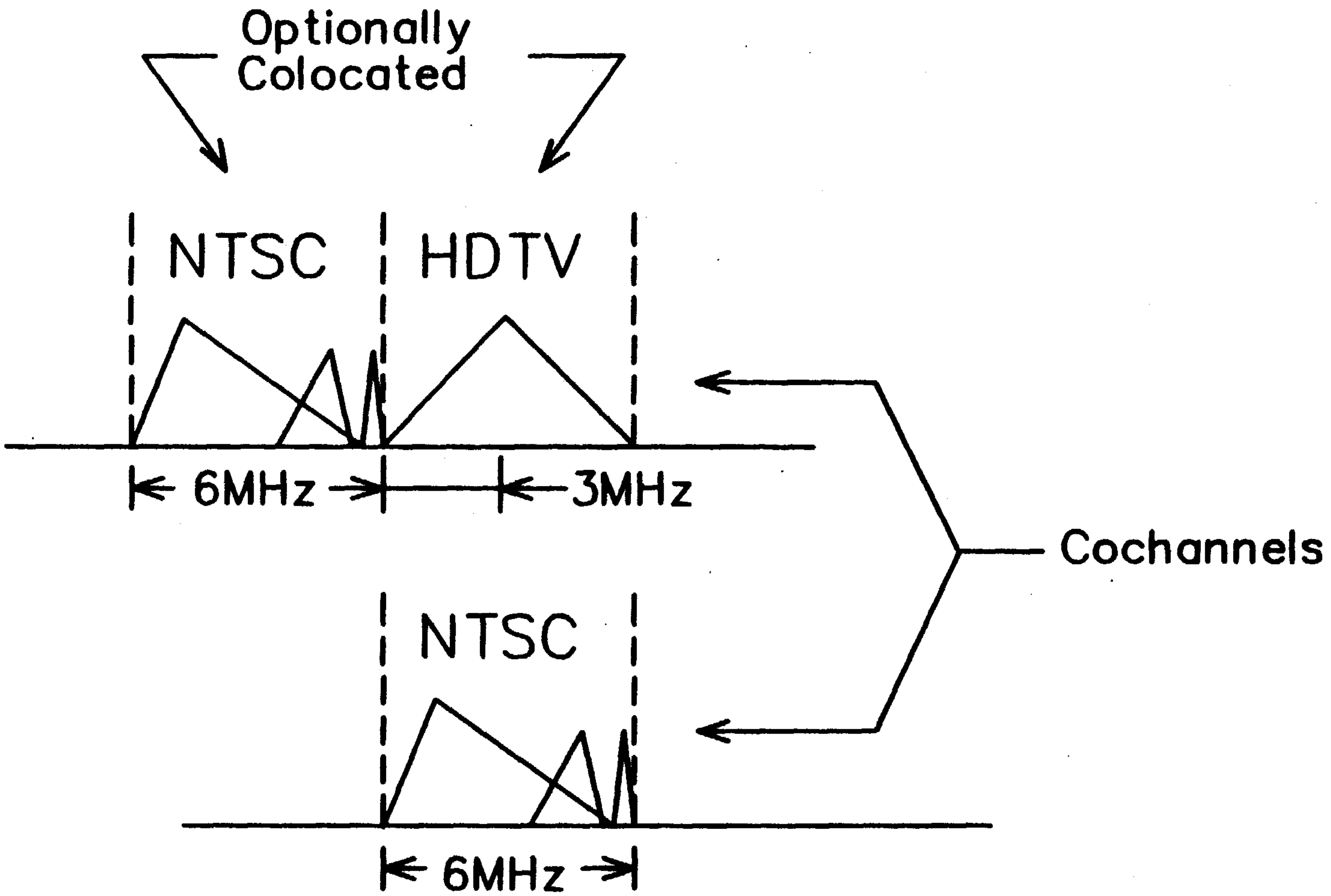
4. TRANSMISSION AND MODULATION TECHNIQUES

4.1 MODULATION FORMAT

As mentioned previously, the optimum use of the 6 MHz channel in a Taboo environment dictates the use of suppressed carrier amplitude modulation of two quadrature carriers located in the center of the channel without the use of any subcarriers. NTSC related scanning standards are used so that precise offset may be used to interleave the HDTV signal into existing NTSC signals for minimum visibility of interference.

In the proposed system, both the data and video are time multiplexed and modulated onto the same two quadrature carriers. The data is transmitted during the vertical interval which may be optionally frame-locked to any NTSC channel which might be susceptible to interference from the HDTV signal. Since data is the most visible interference, frame-locking assures that the VBI data will be hidden in the vertical blanking time of the NTSC channel. Propagation delay differences within the service areas will introduce slight offsets in the VBI's, but not enough to expose the HDTV data in the active video of the NTSC cochannel.

The spectrum of the HDTV channel in relation to the NTSC channels around it is shown in Fig. 4-1. As indicated in Fig. 4-1, when allocated next to an existing NTSC channel, the HDTV channel may be colocated within 10 kM of the NTSC channel, or alternatively, located at least 20 kM outside of the NTSC channel grade B contour. Colocation assures that the U/D ratios are low throughout the service area.



Spectrum Location of HDTV Channel

Figure 4-1

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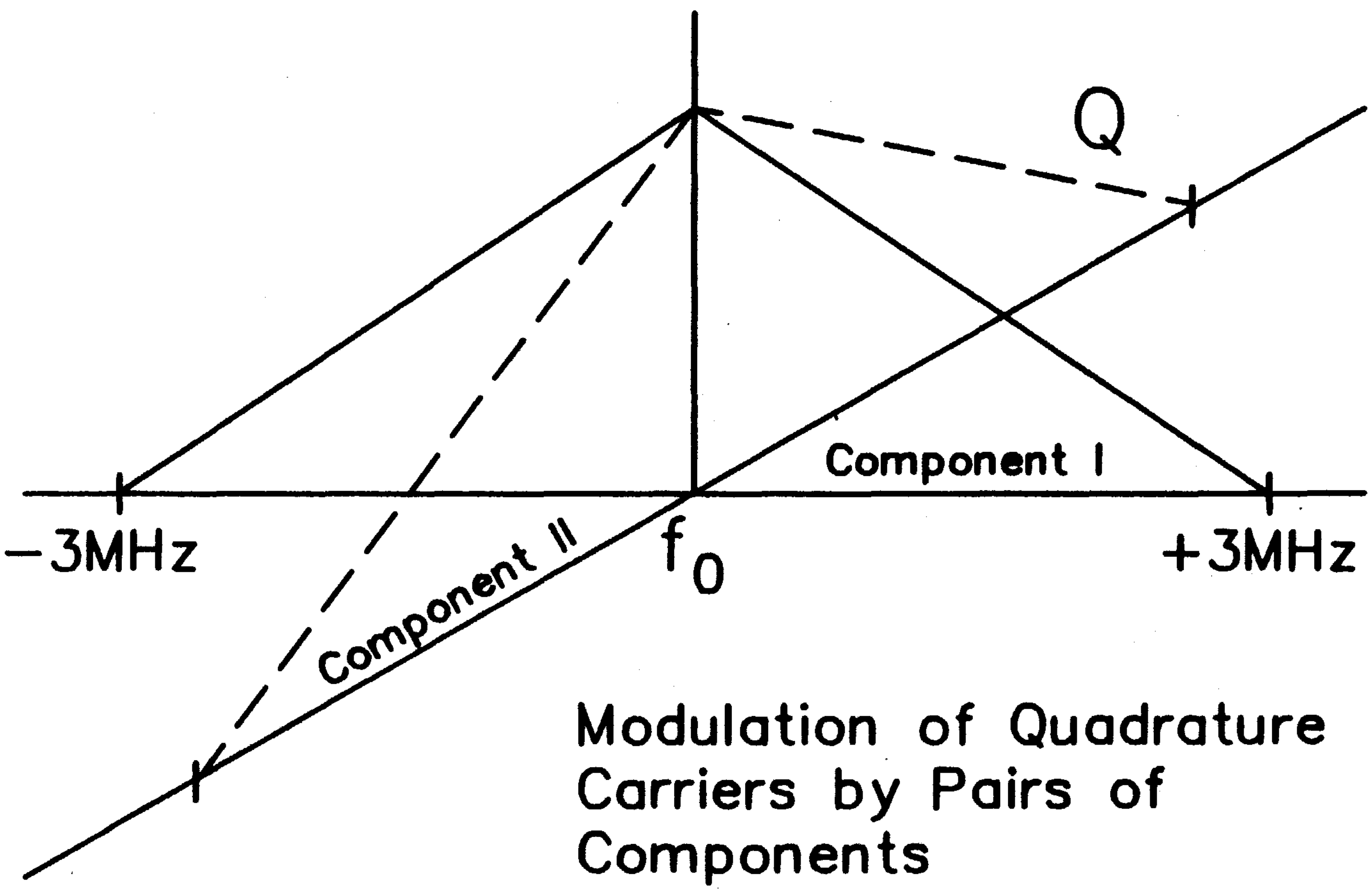
rfspctm

The quadrature modulation used in the channel is illustrated in Fig. 4-2. A pictorial of the components which modulate the I and Q carriers is shown in Fig. 4-3. Each signal which modulates the I and Q carriers, starts with 2 lines of synchronization, and 20 lines of 4-level data. This is then followed by the first group of 240 lines of analog components, 2 more synchronizing lines, 21 lines of 4-level data, and finally a second group of 240 lines of analog components. Fig. 4-3 shows how the non-integer number of lines per frame produces a modulation pattern which repeats at a 29.97 Hz rate. This is analogous to the odd and even fields in NTSC. The 16 QUAM data is produced by modulating both the I and Q channels with 4-level data.

4.2 CHANNEL SHAPING

Since all the encoder processing is performed digitally, the signals available for transmission are all derived from a digital-to-analog converter or a sample-and-hold which both produce a "boxcar" type waveform. It is recognized that this type of waveform has an inherent (sin x)/x shape added to it which must be considered. The compensation for the (sin x)/x shape can easily be accommodated in the transmitter and will be ignored in the following discussion for simplicity sake.

The desired overall channel shape, including both transmitter and receiver, and ignoring the (sin x)/x compensation, is shown in Fig. 4-4. The channel is flat for 2.35 MHz on either side of the carrier frequency and then drops off with a Nyquist slope centered around 170 x 15.734 kHz = 2.675 MHz from the carrier frequency. In addition, for proper data recovery, the overall channel must be designed for linear phase. This particular channel shape was chosen because it provides reasonable transition regions



Modulation of Quadrature Carriers by Pairs of Components

Figure 4–2

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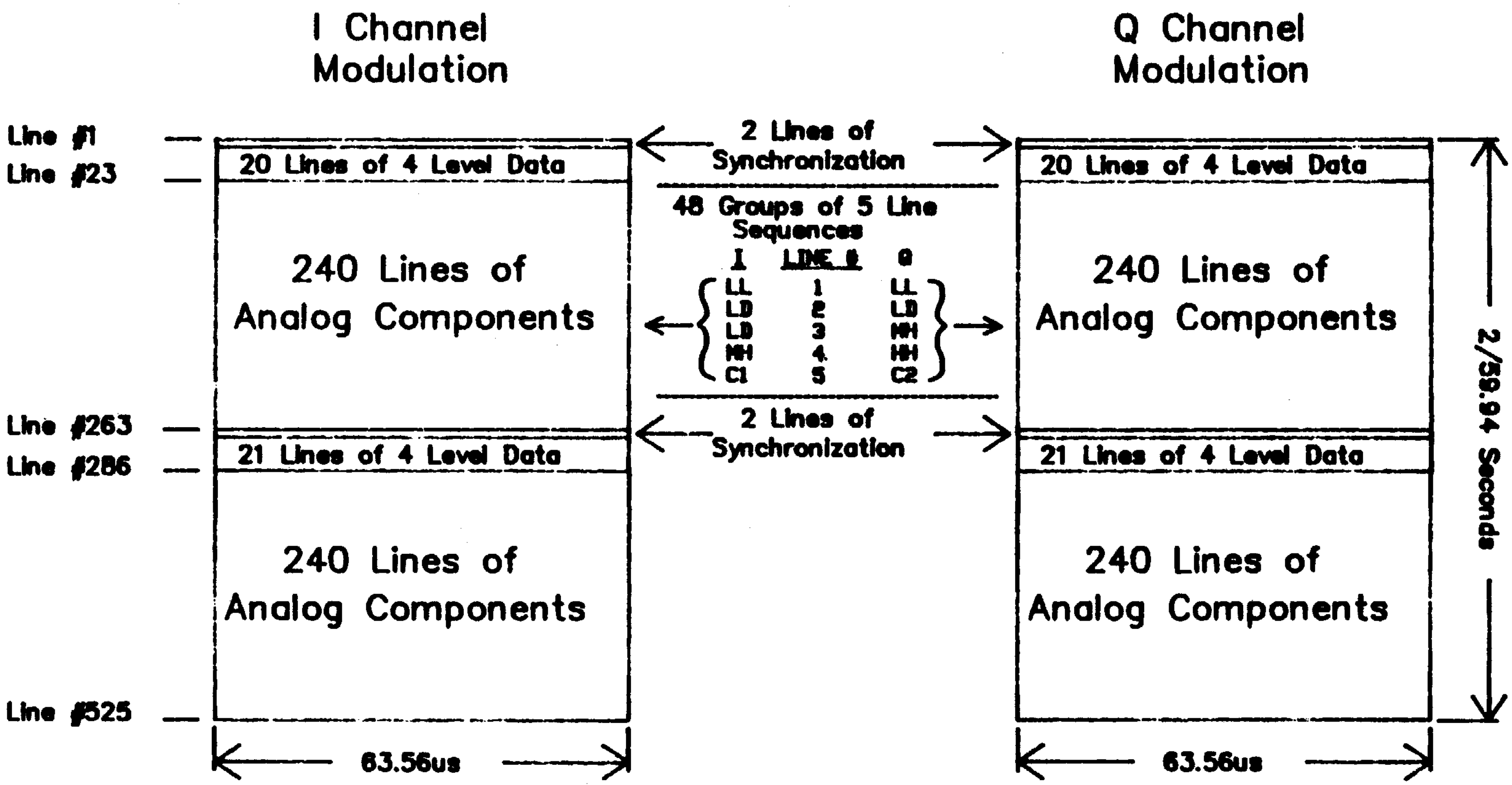
fig_4–2



Modulation on I and Q Channels

Fig 4–3

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fig_4-3

Overall Channel Shape

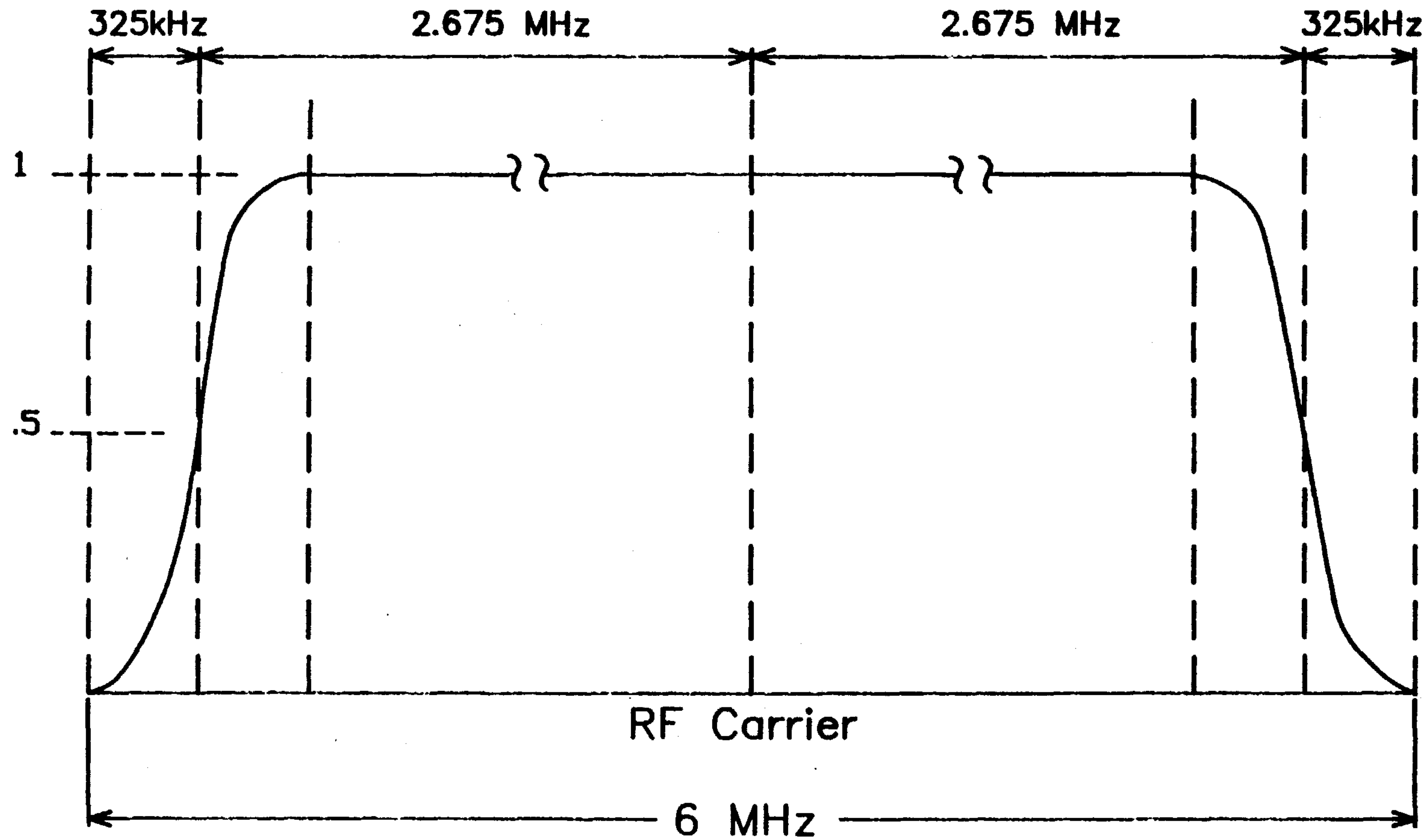

Figure 4–4

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fig_4–4

((

while maximizing the data rate and minimizing the intersymbol interference. Half the bit clock rate is equal to the frequency corresponding to the center of the Nyquist slope.

Surface acoustic wave filters are used in both the transmitter and receiver to precisely control the channel shape. The transmitter bandshaping complements the receiver shape to provide the overall desired response.

4.3 TECHNIQUES FOR FURTHER INTERFERENCE REDUCTION

Although the modulation format contributes significantly to making the Zenith Spectrum Compatible System optimal in a Taboo environment, further improvements in interference reduction are achieved by additional signal processing steps. These steps are applied to the signals which modulate the I and Q channels at the transmitter and each have complementary processes in the receiver. Some of these steps were briefly covered in Section 2, but are discussed here in more detail.

The steps and their complementary receiver processes are:

Transmitter Process	Receiver Process
temporal pre-emphasis	temporal de-emphasis
instantaneous compression	instantaneous expansion
dispersion	inverse dispersion
high-frequency pre-emphasis	high-frequency de-emphasis

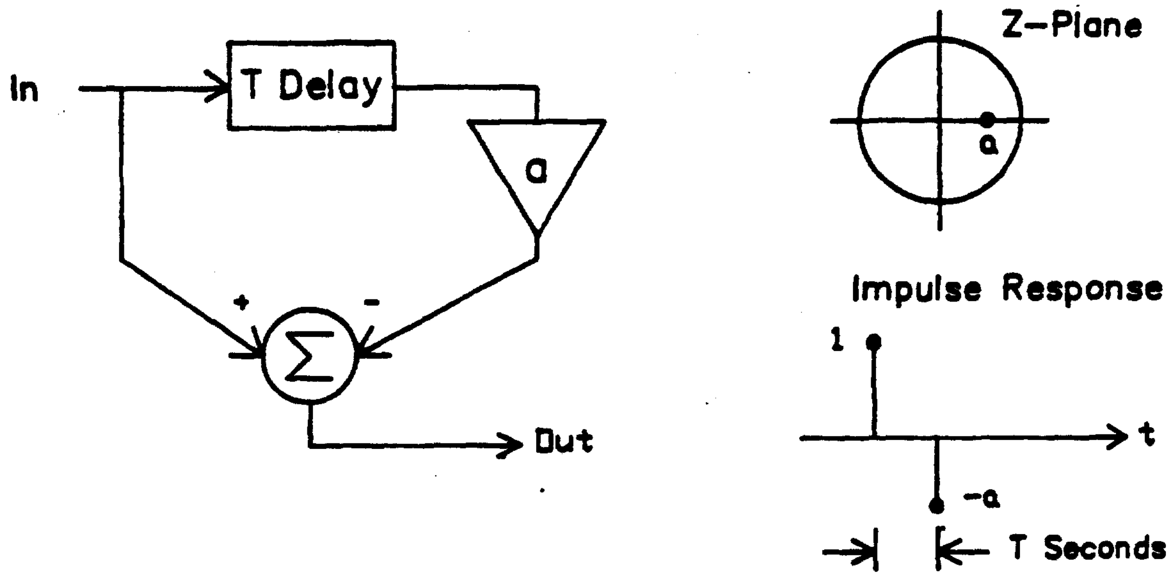
4.3.1 TEMPORAL PRE- AND DE-EMPHASIS

The temporal pre- and de-emphasis reduces interference in two ways. First, it reduces interference caused by the HDTV signal by reducing the transmitted HDTV power for static images. Second, the temporal de-emphasis in the HDTV receiver reduces interference and noise received by the HDTV receiver. In difficult situations where there is a dominant NTSC cochannel, if precise offset to that channel is used, the temporal de-emphasis will also greatly reduce the interference from the NTSC cochannel into HDTV.

A temporal pre-emphasis filter is shown in Fig. 4-5. It is a finite impulse response (FIR) filter with one zero at z=a. Its frequency response is cyclic. At zero temporal frequency (static images) its frequency response starts at a minimum of 1-a, and rises to a maximum of 1+a at temporal frequencies of 1/2T. The effect of temporal pre-emphasis is to reduce the transmitted signal power for static images by 1-a. Moving images will be transmitted at higher signal power but only the fastest moving images will reach the peak of the response at 1/2T. On the average, television pictures are relatively static and for this reason, the temporal pre-emphasis is effective in reducing interference.

The complementary temporal de-emphasis filter is shown in Fig. 4-6. This filter is an infinite impulse response (IIR) filter with a single pole at z=a, which cancels the zero of the transmitter temporal pre-emphasis filter. The combined frequency response of the encoder pre-emphasis and the receiver de-emphasis is flat. The de-emphasis filter output is simply a weighted sum of the current input and all the previous inputs, from previous frames. The response of the temporal de-emphasis filter at zero temporal frequency (static input) is at a maximum of 1/(1-a) while the response to signals at a temporal frequency of 1/2T is at a minimum of 1/(1+a). When precise offset is practiced, the static portions of the NTSC cochannel interference can be made to appear as 1/2T temporal frequency components and thereby be reduced by a factor of 1/(1+a).

Temporal Pre-emphasis Filter



Frequency Response of
Temporal Pre-emphasis Filter

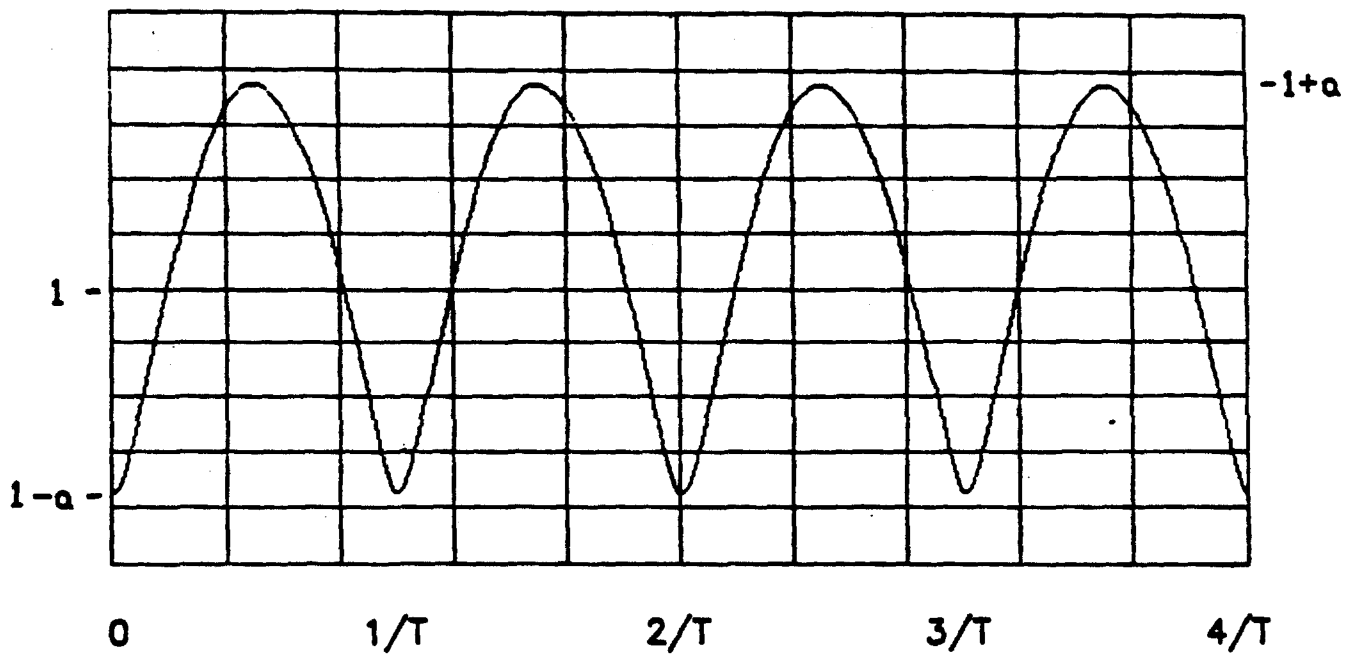


Figure 4-5

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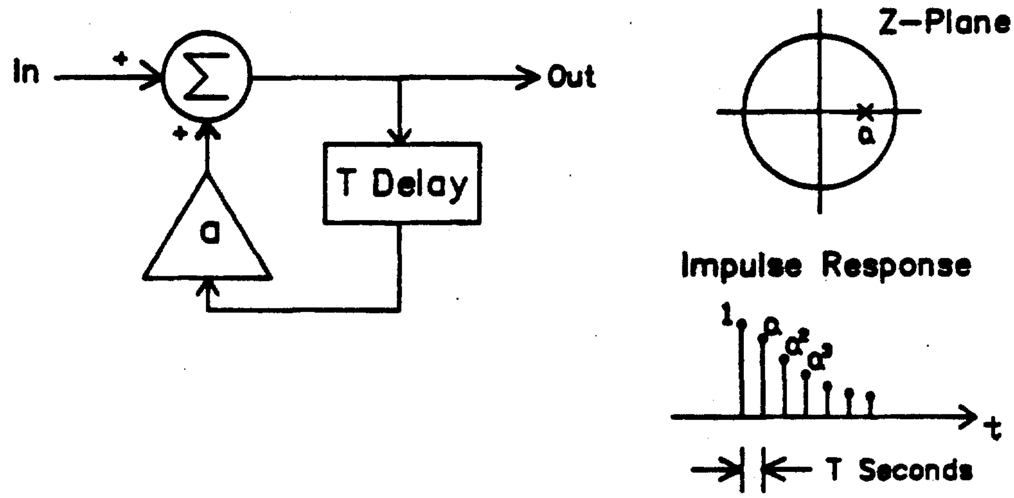
Temporal De-emphasis Filter



Frequency Response of Temporal De-emphasis Filter

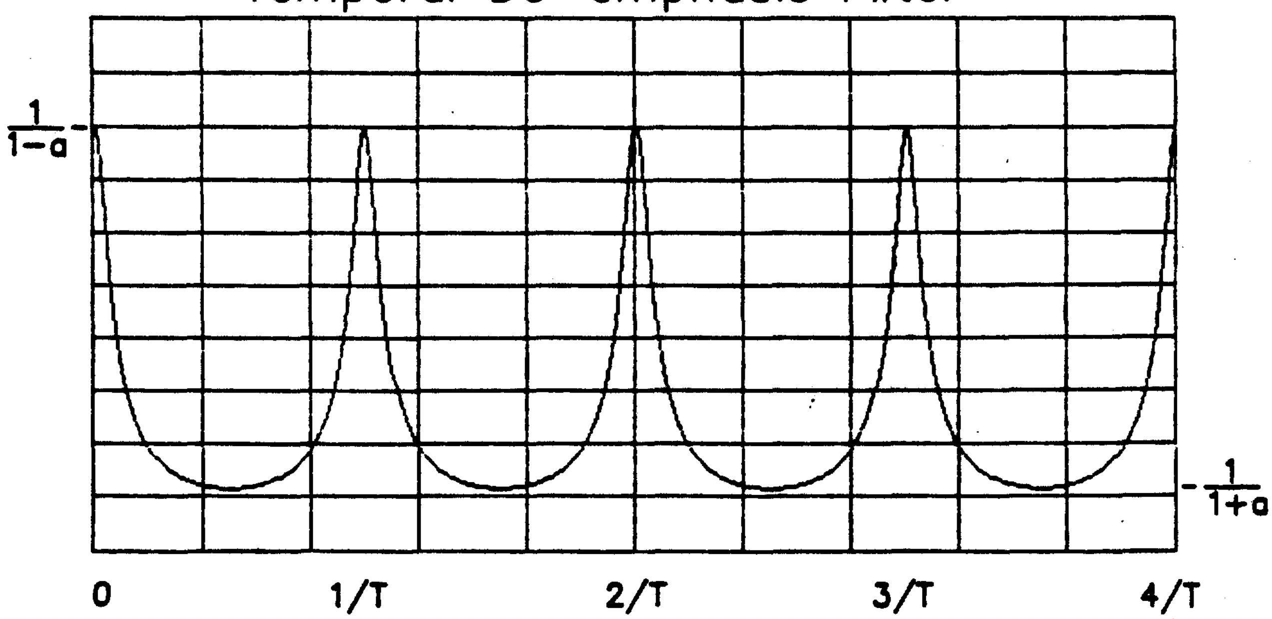


Figure 4–6

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temp_de

Since the video encoding scheme actually has two basic frame rates, 59.94 fps for the LL components and 11.988 fps for all the other components, two sets of temporal pre-emphasis and de-emphasis filters are used. One for the LL components, and one for all the other components. The parameters for the temporal pre-emphasis filters are as follows:

LL components: $T = 1/59.94$ seconds, $a = 0.75$
Other components: $T = 1/11.988$ seconds, $a = 0.5$

The temporal pre-emphasis filter for the LL components reduces the stationary LL information between adjacent frames to 1/4, or 12 dB, while the LL temporal de-emphasis filter reduces the NTSC cochannel interference to 0.57, or 4.86 dB.

For the other components, the temporal pre-emphasis reduces the amplitude of the stationary components (stationary over 1/11.988 sec) to 0.5, or 6 dB, and the temporal de-emphasis in the receiver reduces the NTSC cochannel interference to 0.67, or 3.5 dB. Note that since the NTSC cochannel interference is periodic in 29.97 Hz, it is also periodic in 5.994 Hz which corresponds exactly to 1/2T for the temporal de-emphasis used for the other components.

Measurements of interference have shown that even without the power reduction resulting from temporal pre-emphasis, interference caused by the HDTV signal into NTSC services is quite low, even at worst case interference levels. As a result, in practice, the reduction in power for static images is used not only for the benefit of decreasing transmitted power, but instead, additional rejection of the NTSC cochannel is derived. By raising the transmitted power for static images, when temporal pre-emphasis is used, cochannel interference into the LL component of the HDTV signal can be reduced by up to 16.86 dB, the sum of 12 dB and 4.86 dB. The reduction of NTSC cochannel interference into the other HDTV components can be as much as 9.5 dB, the sum of 6 dB and 3.5 dB.

In choosing the value of the coefficient 'a' for the temporal de-emphasis filters, one very important consideration is the decay time of the receiver filter. Any impulse noise which is passed on to the de-emphasis filter is stretched out in time and could be made more visible. For this reason, the coefficient 'a' is reduced, for the filters with the longer delay, T=1/11.988 seconds.

The temporal pre- and de-emphasis filters are shown in the encoding and decoding block diagrams shown in Fig. 3-4, 3-10, and 3-11.

4.3.2 INSTANTANEOUS COMPRESSION AND EXPANSION (COMPANDING)

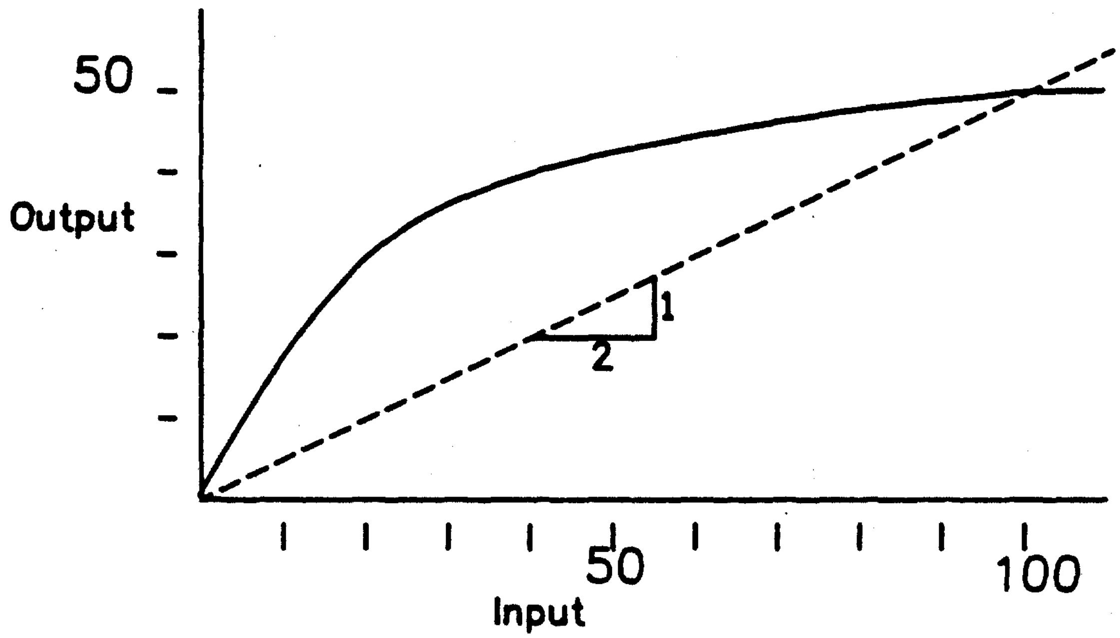
The use of temporal pre-emphasis and low-frequency removal, reduces the power of the transmitted signal and significantly reduces interference caused by the HDTV signal. The remaining interference results predominately from high peak power occurring on moving edges where both the low-frequency removal and the temporal pre-emphasis are not as effective in reducing power.

To lower the transmitted peak power, instantaneous compression is used in the transmitter, and complementary instantaneous expansion is used in the receiver.

The compressor is a nonlinear transfer function that operates on the instantaneous amplitude of the HDTV components. Its purpose is to raise the level of low amplitude signals and to lower the level of high amplitude signals. Fig. 4-7 shows the compressor curve. Low amplitude signals are raised by a factor of two, and high amplitude signals are lowered by a factor of two. By lowering the high amplitude peaks of the transmitted signal, interference caused by them is reduced. Due to the nonlinear origins of many interferences, the visibility of the interference often decreases exponentially with the reduction of peak power.

The increase in low amplitude HDTV signals helps to reduce the effect of NTSC interference into HDTV. Since the low amplitude signals are raised, the signal-to-noise ratio of these signals is improved. By only boosting low amplitude components, the resulting HDTV signal is still relatively small, and interference into NTSC arising from nonlinear mechanisms is not significantly increased.

In the HDTV receiver, a complementary expander characteristic is used to restore the signal to its proper amplitude. The expander curve is shown in Fig. 4-8. The use of the expander in the receiver also serves to reduce the interference into HDTV from NTSC. This happens for two reasons. First, NTSC interference into the HDTV signal is always expected to be of low amplitude, and second, the only time the HDTV signal has high amplitude is on moving edges. In the HDTV receiver, the received signal is the sum of a low amplitude interference along with the HDTV signal itself. In areas of little detail in the HDTV image, where the interference will be the most visible, the sum of the two components will have a low amplitude and the expansion curve reduces them by a factor of two. During moving edges



Encoder Compressor

Figure 4-7

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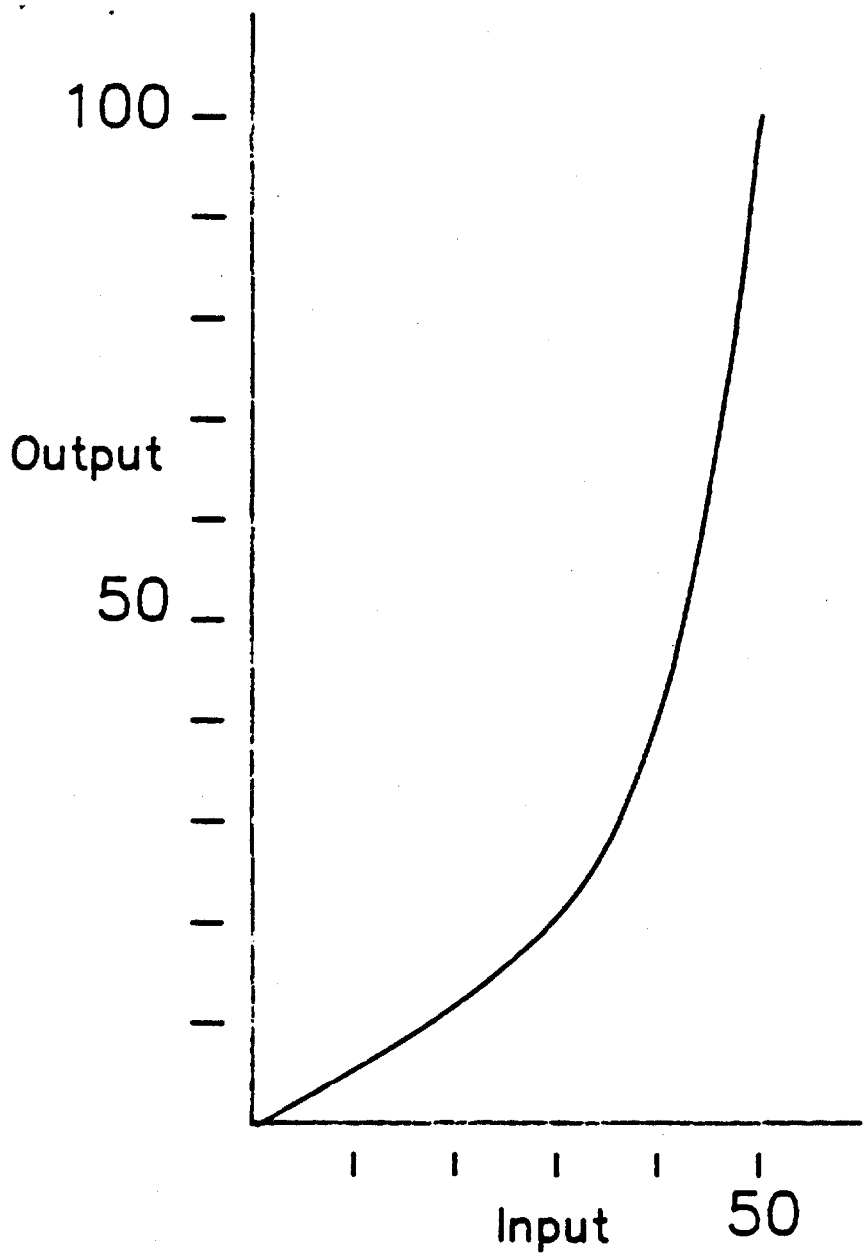
fig_4-7



Decoder Expander
Figure 4–8

Zenith
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fig_4–8

in the HDTV picture, where the interference is least visible, the sum of the interference and the HDTV signal has a high amplitude and the expansion curve increases their amplitudes by two. The result of this process is that the interference becomes multiplicative and is shifted from low detail areas to high detail areas where it is less visible. The use of companding hides or masks the interference into the HDTV signal. Noise is also masked by the same effect.

It is realized that the instantaneous compression process may create distortion products of the video signal which cannot be transmitted in the 6 MHz channel and must be filtered out. The fact that these distortion products are not transmitted, may result in inaccurate restoration by the expander and create a net video distortion on edges. The maximum distortion will appear on maximum peak signals which due to the temporal pre-emphasis and low-frequency removal, only occur on moving edges. This effect should be quite tolerable and probably even unnoticeable. Since the distortion results in a reduction in peak amplitude, the amplitude of the high level peaks may be restored with linear peaking. Linear peaking will partially restore the distorted peaks and simply peak the low amplitude signals.

4.3.3 DISPERSION AND INVERSE DISPERSION

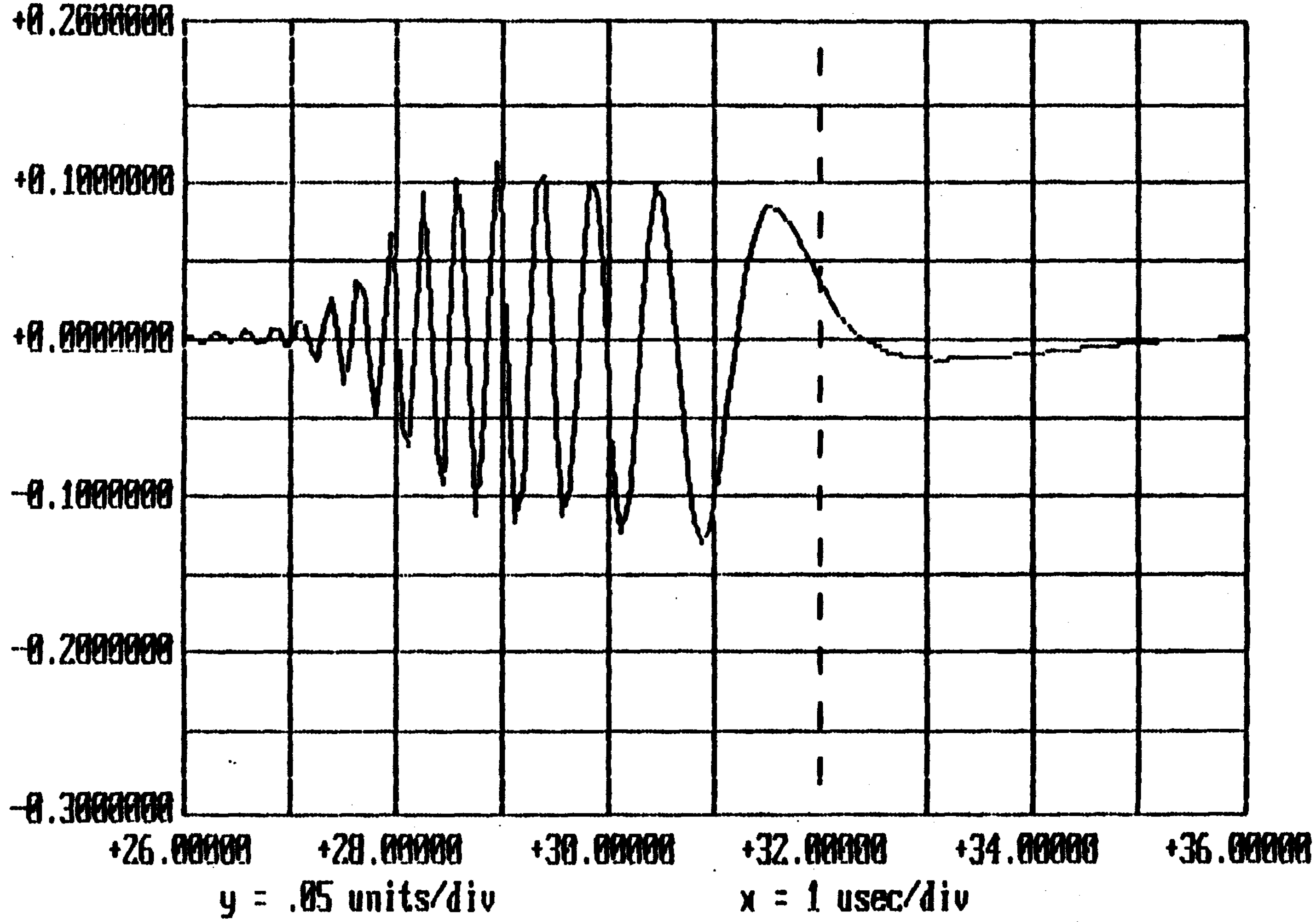
After the low frequencies are removed from the analog portion of the HDTV signal, the highest amplitude HDTV signal peaks occur only as pulses. Since interference from the HDTV signal into NTSC may be exponentially proportional to the peak signal power, a linear filter is used to reduce the amplitude of the pulses by dispersing their energy over time.

Fig. 4-9 shows the impulse response of a dispersive filter. This filter, which is also known as a chirp, has a flat magnitude response and a group delay which changes linearly with frequency. Pulses passed through this filter are stretched out in time and reduced in amplitude. The impulse response of the inverse chirp filter is simply the time inverse of Fig. 4-9.

At the transmitter, a dispersive filter is used on each of the I and Q modulating signals to reduce the peak signal. At the receiver, inverse dispersive filters are used to restore the signals. The use of dispersion and inverse dispersion will help alleviate interference in two ways. First, peaks in the HDTV signal will be reduced in amplitude and dispersed over time thereby reducing the visibility of HDTV interference into an NTSC channel. Secondly, the receiver inverse dispersion will spread any interference into the HDTV receiver over time and thereby reduce its visibility.

4.3.4 HIGH-FREQUENCY PRE- AND DE-EMPHASIS

High-frequency pre-emphasis and de-emphasis of the analog video components modulated on the I and Q axis is used to improve the interference and noise performance of the HDTV signal. The I and Q modulating signals are pre-emphasized at the transmitter and de-emphasized at the receiver. Since the typical video spectrum rolls off at higher frequencies, boosting the high-frequencies before transmission tends to flatten the transmitted spectrum. The de-emphasis at the receiver restores the spectrum to its original shape and at the same time reduces any high-frequency noise and interference. Note that due to the use of quadrature carriers in the center of the HDTV channel, components around the picture carrier of a NTSC cochannel



Impulse Response of Dispersive Filter

Figure 4—9

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appear as 1.75 MHz interference components and are reduced by the de-emphasis. Since the received I and Q signals are digitized in the HDTV receiver for processing, the reduction of NTSC picture carrier interference is very important since the A/D converters in the HDTV receiver must also include headroom for the interference.

Although the use of pre-emphasis boosts the transmitted HDTV signal level, measurements have shown that the interference caused by the HDTV signal into NTSC is still quite low.

In the receiver, the de-emphasis is incorporated as part of the I.F. filter which results in a "haystack" shaped I.F. filter centered around the carrier frequency. The "haystack" receiver shape allows the simplest and most economical filter design in the receiver with excellent adjacent channel rejection. Of course the pre-emphasis in the transmitter results in a transmitter filter which has steep skirts and is more complicated than the filter required in the receiver.

4.4 SYNCHRONIZATION SYSTEMS

In the Zenith HDTV transmission format three synchronizing signals are needed for video and data synchronization. An RF carrier, high frequency clock, and field rate synchronizing signals are required. These three signals require less than 1% of the power and less than 1% of the transmission time. In contrast to this, NTSC carrier synchronization is provided by the first 20 units of unmodulated picture carrier, while the NTSC video synchronization is provided by the color burst signal, horizontal sync signal and vertical field and frame rate signals. These signals combined with video blanking signals require over 60% of the power and greater than 26% of the transmission time. Despite the significant increase in synchronization efficiency of the HDTV format, the HDTV format is very rugged. Under conditions such as heavy white noise, impulse noise or multi-path interference, the new format provides superior synchronization compared to NTSC. This increased performance is made possible by the use of digital correlation filters and very narrow-band phase-locked loops with stable crystal oscillators.

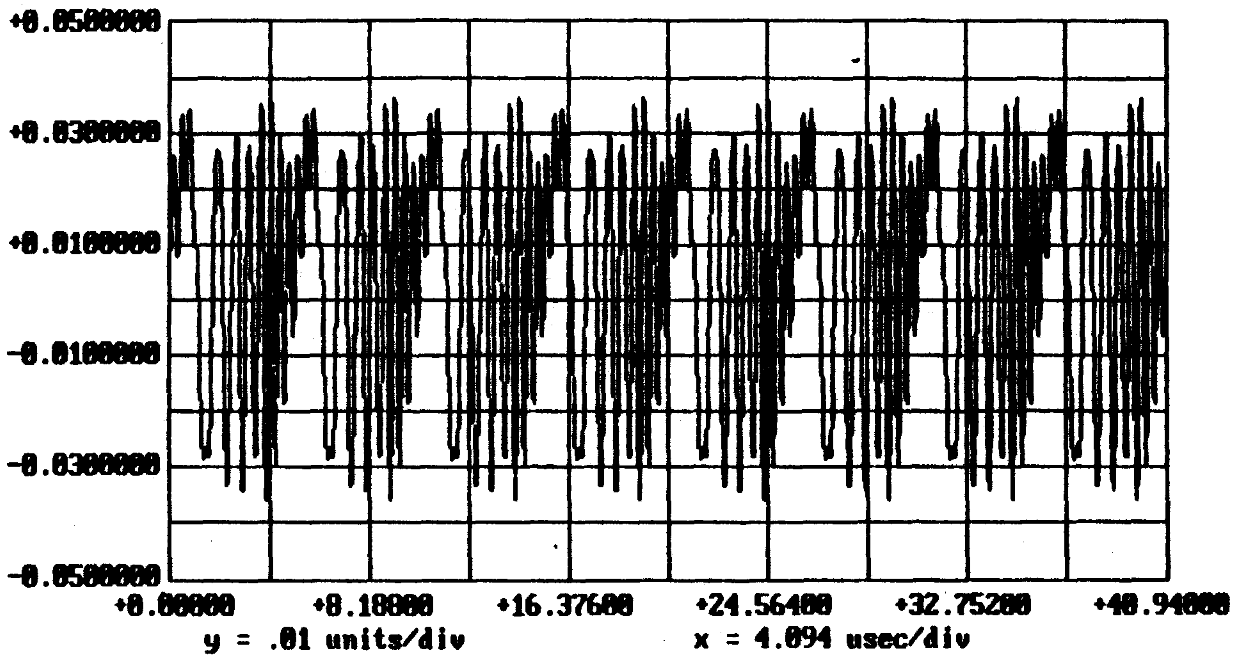
4.4.1 CARRIER SYNCHRONIZATION

The video information is carried by two double sideband suppressed carrier signals in quadrature. Since the low-frequency information below 15 kHz (including d.c.) has been removed from all video components, the picture carrier is nulled and a small pilot carrier is added to aid RF carrier recovery. This pilot carrier is used by a very narrow-band phase-locked loop to regenerate the picture carrier. The loop integrates over more than 5 video lines (318 uS). At this bandwidth, very high signal-to-noise ratios are achieved even with a very small pilot carrier. By using the pilot carrier and narrow band PLL's, linear detection is maintained even under severe multi-path conditions. This happens because the system synchronizes to the vector sum of the signal and ghost, integrated over several line periods, which is guaranteed by the removal of low-frequency video information to be a constant only dependent on the pilot carrier and its ghost. With the linearity of the video detectors maintained even under severe ghosts, the in-phase and quadrature video components can be processed by a digital channel equalizer (ghost eliminator), to reduce ghosts and other linear channel distortions, without the problems that nonlinearities have introduced into such systems in the past. A proposal for channel equalization is beyond the scope of this HDTV proposal but it is pointed out that the detector linearity permits introduction at some later time.

To use a very narrow band synchronous detector a wideband acquisition system is required. A frequency and phase-lock loop is used. In its frequency or acquisition mode the loop is capable of acquiring a signal which is hundreds of times the phase-locked loop's bandwidth. Once acquired the frequency loop will not contribute any noise to the narrow band phase-locked loop.

4.4.2 HIGH FREQUENCY CLOCK SYNCHRONIZATION

One of the two synchronizing lines during the vertical interval is used for the high-frequency clock synchronizing signal. A simple sine wave in combination with a narrow band frequency and phase locked loop regeneration system is used to achieve a very high signal-to-noise ratio. This is made possible by a very stable crystal oscillator. For superior ghost performance a more elaborate system may be used. At the encoder, the high frequency clock is counted down forming a periodic chain of very high amplitude narrow pulses. These pulses are then processed by a dispersion or chirp filter producing a chain of chirp signals shown in Fig. 4-10. This signal is then transmitted. In the receiver an inverse chirp filter is used to reform the original high amplitude chain of narrow pulses. If during transmission the signal is corrupted by a ghost, the receiver will recover the original pulses followed by smaller ghosts. If the received signal is sliced by a comparator or data slicer with a level set above the ghost pulses, the original pulse chain can be recovered with the



Chain of Chirps Synchronizing Signal

Figure 4—10

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ghost eliminated as shown in Fig. 4-11. This clean pulse train can then be used to regenerate the high-frequency clock.

The use of dispersion filters in this process improves the S/N ratio of the received signal without the corresponding increase in peak power. The dispersion filter is used here for the same reasons that it is used in radar.

4.4.3 FIELD RATE SYNCHRONIZATION

A chirped signal of long duration is inserted into one line of the VBI for the field rate synchronizing signal. In the receiver a digital inverse chirp filter is used to recover the signal. The process gain of this digital correlation filter is considerable, yielding a synchronizing signal that is immune to random noise, impulse noise, interference, and ghosts.

This same chirp signal can also serve as an ideal training signal for channel equalization (ghost canceling).

4.4.4 AUTOMATIC GAIN EQUALIZATION SYSTEM

The video signal is transmitted in two parts. The low-frequencies are transmitted digitally, the high-frequencies are transmitted as an analog signal. In the receiver it is essential to match these two signals. In the receiver the automatic gain control must be very accurate and immune to common signal degradations. An automatic gain equalization system is used for this task. It is a two-point system that automatically adjusts for zero carrier offsets and for gain variations. By appropriately sampling and filtering the reference chirp signals in the vertical interval, both of these tasks are accomplished.